Plant and Microbial Responses to Sorghum-Soybean Cropping Systems and Fertility Management

W. RODER, S. C. MASON,* M. D. CLEGG, J. W. DORAN, AND K. R. KNIEP

ABSTRACT

Monoculture production of soybeans (*Glycine max* (L.) Merr.) and grain sorghum (*Sorghum bicolor* (L.) Moench) generally results in declining grain yields. To better understand biological and chemical interactions causing yield declines with continuous cropping, microbial biomass, crop root dry weight, soil organic matter, and total N content were measured in a cropping system experiment on a Sharpsburg silty clay loam (Typic Argiudoll). The cropping treatments included continuous soybeans, continuous sorghum, and sorghum-soybean or soybean-sorghum rotations. These treatments were initiated 5 y prior to taking the reported measurements. Fertilizer treatments consisted of no amendment (control), N (45 kg ha^{-1} on soybean plots and 90 kg ha^{-1} on sorghum plots), and manure applied at 15.8 Mg dry matter ha^{-1} yr^{-1}. In summer 1986, the microbial biomass C for the 0–30-cm layer of soil averaged across fertility treatments was 1.37, 1.49, 1.43, and 1.58 Mg ha^{-1} for continuous soybeans, rotated soybeans, rotated sorghum and continuous sorghum, respectively. Soil microbial biomass C and soil organic matter contents for manured treatments were 11 to 14% and 6 to 16% greater, respectively than those of unfertilized controls. Root dry weights for the 0–30-cm depth were 26 and 77% higher for soybeans and sorghum if the previous crop was sorghum instead of soybeans. In summer 1986, microbial biomass in the 0–15-cm depth was correlated with root density and water-filled pore space in sorghum plots and with bulk density in soybean plots. Previous crop, present crop, and fertilizer treatment affected dry matter partitioning between above- and below-ground plant parts and microbial biomass. With sorghum as a previous crop, a higher proportion of the total production occurred below ground as roots and microbial biomass.

W. Roder, S. C. Mason, M. D. Clegg, and K. R. Kniep, Dep. of Agronomy, Univ. of Nebraska, Lincoln, NE 68583; and J. W. Doran, USDA-ARS, Soil and Water Conservation Research Unit, Lincoln, NE 68583. Partial financial support was provided by the Int. Sorghum and Millet Collaborative Research Program (INTSORMIL), U. S. AID grant DAN-1254-G-SS-5065-00. Joint contribution of Nebraska Agric. Res. Div. and USDA-ARS. Nebraska Agric. Res. Div. Journal No. 8445. Received 14 Sept. 1987. *Corresponding author.

Published in Soil Sci. Soc. Am. J. 52:1337–1342 (1988).

SOYBEANS AND SORGHUM are major dry land crops in the Great Plains for which crop rotation and N fertilization generally result in greater grain yields. The reasons why rotation sequences increase yields, however, are poorly understood. Depending on crop species and sequences used, crop rotations generally result in higher soil organic matter contents than continuous cropping systems (Hageman and Shrader, 1979; Smith and Henderson, 1967; Adams 1974). Increased soil fertility, higher biological activity, and better physical properties of the soil are the most commonly cited benefits attributed to organic soil amendments. The effect of manure applications on the soil organic matter is well documented (Unger and Stewart, 1974; Bosch and Amberger, 1983; Campbell et al., 1986; Sommerfeldt and Chang, 1986). Effects of soil management systems on soil organic matter were discussed in a recent review by Doran and Smith (1987). Microorganisms make up only 1 to 8% of the total soil organic matter but largely influence crop production through acting as catalysts for transformations of N and other nutrients (Doran and Smith, 1987; McGill et al., 1986). Several authors have shown close relationships between microbial biomass and soil organic matter content or soil N level (Adams and Laughlin, 1981; Beck, 1985; Ross et al., 1980).

Crop rotation (Beck, 1985; Biederbeck et al., 1984; McGill et al., 1986), manure treatment (Adams and Laughlin, 1981; Rosswall and Paustian, 1984), and fertilizer treatment (Bolton et al., 1985; Lynch and Panting, 1982) has been shown to affect microbial biomass. Interactions between rotation treatments and organic soil amendments or fertilizer treatments on microbial biomass, however, have received little attention.

Crop rotation or fertilizer treatments, or both, can greatly influence root growth. Fahad (1979) showed that root density (length volume^{-1}) of continuous soybeans were 38% lower than soybeans in rotation with corn (*Zea mays* (L.)) or sorghum. The size and activity of the soil microbial biomass is also influenced by root growth and root exudates (Wood, 1987). Exudates provide a source of energy and C for microorganisms. Considering the close relationship between root growth and microbial activity, cropping practices affecting root growth should similarly affect microbial biomass.

A rotation experiment, initiated in 1981 to quantify yield reductions caused by continuous soybean cropping, was used to study soil biological and chemical interactions occurring with different cropping systems. Because soil fertility often declines with monocropping and soybean cropping is known to negatively affect soil physical properties (Fahad et al., 1982), manure and N fertilizer treatments were also included in this study.

The objectives of this study were to: (i) determine the effects of cropping system, manure, and fertilizer N on microbial biomass, root production, soil organic matter and total soil N in a sorghum-soybean rotation, and (ii) identify possible relationships between microbial biomass and crop root production, soil organic matter content, and soil N content.

MATERIALS AND METHODS

The experiment was conducted at the Univ. of Nebraska Research and Development Center near Mead, Neb. on a Sharpsburg silty clay loam (fine montmorillonitic, mesic, Typic Argiudoll). The cropping treatments of continuous sorghum, continuous soybeans, sorghum-soybean rotation and soybean-sorghum rotation were initiated in 1980. Fertilizer treatments consisted of no amendment (control), manure (15.8 Mg dry matter ha^{-1}), and fertilization N (45 kg ha^{-1} for soybeans, 90 kg ha^{-1} for sorghum) were applied yearly since 1981. Manure at 14.4 and 13.3 Mg ha^{-1} (193 and 167 kg N ha^{-1}) was applied on 26 March and 27 March in 1985 and 1986, respectively. Nitrogen was applied 3 to 4 wk after planting as liquid urea-ammonium nitrate through 1985 and as ammonium nitrate (33% N) in 1986. The experiment was a split-plot randomized complete block design with four replicates. The whole plot treatment alternated yearly changing from present crop in even years to previous crop in odd number years. Consequently the power for testing previous crop effects was reduced in 1985. The plots were 12 rows wide, with rows spaced 0.75-m apart. Rows were 7.8-m long. Tillage was uniform for all treatments and generally consisted of disking after manure application and double disking before planting. Planting dates were 22 and 23 May in 1985 and 14 May in 1986. As a result of heavy surface crusting, rotary hoeing was used on the sorghum plots in 1986.

Microbial Biomass

Soil samples were taken at depth increments of 0–15 and 15–30 cm in 1985 and 0–7.5, 7.5–15, and 15–30 cm in 1986. Samples were collected from the middle 4 m of the 4 center rows with a 17-mm diam. sampling tube. Each sample consisted of a composite of two samples collected in the row and eight samples collected between rows. Sampling dates were 17 June and 31 October in 1985 and 28 May, 25 August, and 30 October in 1986. Samples taken in spring after planting were expected to reflect previous crop effects, while samples taken in fall (after harvest) were expected to reflect the effect of the present crop. Soil samples were stored at 4 °C for no longer than 10 d prior to sieving and analysis. A 2-mm mesh sieve was used in 1985, whereas in 1986 a 4.8-mm mesh sieve was used due to moist condition of samples.

Microbial biomass was determined by the substrate addition technique described by Anderson and Domsch (1978) with modifications proposed by Smith et al. (1985). Minimum glucose rates required for maximum CO_2 response were established based on pilot studies made initial to each measuring date. We added 6 and 7 mg glucose kg^{-1} soil for samples 1985 and 1986, respectively. Nutrient additions used were those recommended by Smith et al. (1985). Sieved soil samples were brought to a water content of 20% (w/w) and incubated at 22.5 °C for 5 d prior to substrate addition. Carbon (C) evolved was determined by measuring CO_2 concentration 2 h after incubation with an IR gas analyzer as described by Clegg et al. (1978).

Root Sampling and Measurements

Root samples were taken in 1986, on 31 July (replicate 1) and 27 and 28 August (replicates 2–4), using a tractor mounted Giddings hydraulic soil coring machine. Sampling of blocks 2 to 4 had to be delayed because of wet soil conditions. Three cores (diameter of 4.46 cm) were taken from each plot. One sample was taken directly over the plants, while the others were taken at distances of 19 and 38 cm from the row. The cores were divided into depths of 0 to 7.5, 7.5 to 15, 15 to 30, 30 to 60, 60 to 90, and 90 to 120 cm. Subsamples of the same depth were composited, placed in a plastic bag, and stored at −20 °C until extraction. Root extraction was done following the hydropneumatic elutriation system as described by Smucker (1984). Roots were collected on a sieve of 0.54-mm pore size. After removing the debris (dead plant material, seeds, etc.) root length was estimated by the modified line intercept method (Tennant, 1975). Roots were then dried at 65 °C and weighed. Root length data was used in correlation calculations to evaluate possible relationships with microbial biomass. One-meter length of a center row was harvested at the time of root sampling to estimate shoot dry matter production and total productivity, consisting of plant and microbial dry matter.

Organic Matter and Total N Content

Soil samples collected for biomass measurements in the fall 1986 were subsampled and analyzed for organic matter and total N contents using colorimetric (Schulte, 1980) and Kjeldahl methods, respectively.

Statistical Analysis and Presentation of Data

Estimates on an area basis for microbial C (summer 1986 measurements), organic matter, and total N were made using bulk density values measured for each plot and depth. Bulk density was measured at the time of root sampling using a tractor-mounted Giddings hydraulic soil coring machine. One core (diam of 4.46 cm) was taken from each plot.

Orthogonal contrasts were used to compare the treatment effects. Since crop by previous crop interactions were present

Table 1. Effect of manure and N fertilizer on amount of organic matter, total N, phosphate, K in soil, and soil reaction (pH).†

Categories	Organic matter	Total N	Phosphate	K	pH
	g kg^{-1}		mg kg^{-1}		
Control (C)	25.5	1.53	16.7	396	6.77
Manure (M)	29.6	1.78	74.8	528	6.83
N	24.9	1.46	16.6	386	6.64
Contrasts	(PR > F)				
M vs. C & N	<0.01	<0.01	<0.01	<0.01	0.04
C vs. N	0.40	0.47	0.99	0.57	0.06

† Samples were collected on 25 March 1985 from 0- to 30-cm depth.

for some of the measured quantities, results are presented separately for the two crops. Fertilizer treatment effects were generally more pronounced in the top increment (0–7.5 cm). Since the increment 7.5 to 15 cm followed the same trends, however, only the average response of these two increments is shown in all tables and figures.

RESULTS AND DISCUSSION

The effects of manure and fertilizer N treatment on soil organic matter, soil N, potassium (K), available phosphorus (P) contents, and soil pH for soil samples collected in spring 1985 are shown in Table 1. Amounts of organic matter, total N, K, and available P in manured soil were 16, 16, 33, and 348% greater, respectively, than those in non-manured soil. Compared with the unfertilized control, pH values were higher with manure application and lower with nitrogen application. No effects of cropping treatments were observed.

Microbial Biomass

Estimated values for microbial biomass C for the 0 to 15-cm depth are shown in Table 2. Amounts of microbial C ranged from 47 to 77 mg C per 100 g dry soil depending on sampling date and fertilizer or cropping treatment. No cropping effects were observed in 1985. In 1986, soil biomass C (averaged over all treatments) in the summer and fall were 14 and 27% greater, respectively, than those observed in the spring.

Biomass levels of manure treated soils were 9% (soybean plots in fall 1985) to 25% (soybean plots in spring 1985 and spring 1986) higher than those of corresponding control plots. Effects of manure on soil microbial biomass in the soybean plots were more pronounced in spring than in the fall for each year. Compared with soybeans the biomass C content of soil planted to sorghum was 9 and 5% greater in the spring and fall of 1985, and 12, 9, and 6% greater in the spring, summer, and fall of 1986, respectively.

Estimates of soil microbial biomass on an area basis for the 0 to 15- and 15 to 30-cm depths in August, 1986 are shown in Fig. 1. Biomass C was greatest in continuous sorghum receiving manure, with amounts of 1.28 and 0.46 Mg ha^{-1} for the 0 to 15- and 15 to 30-cm depths, respectively. Total biomass C for the 0 to 30-cm depth, averaged over fertility treatments, was 1.37, 1.49, 1.43, and 1.58 Mg ha^{-1} for continuous soybeans, rotated soybeans, rotated sorghum and continuous sorghum, respectively. Previous crop effects were significant at $P < 0.01$ for soybean plots and $P = 0.03$ for sorghum plots. These estimates are comparable with those reported by others for similar conditions

Table 2. Effect of crop, previous crop and fertilizer treatment on microbial biomass C content of the 0- to 15-cm soil layer in 1985 and 1986.

Categories	1985 Spring	1985 Fall	1986 Spring	1986 Summer	1986 Fall
a. Soybean (present crop)					
	Biomass, mg C kg^{-1} soil				
Previous crop					
Soybean	510	550	470	550	630
Sorghum	550	500	540	610	690
Fertilizer					
Control	480	530	470	550	610
Manure	600	580	590	660	730
N	510	480	470	530	630
Contrasts	(PR > F)				
Previous crop	0.33	0.50	<0.01	<0.01	<0.01
Fertilizer					
Manure vs. others	<0.01	<0.01	<0.01	<0.01	<0.01
Control vs. N	0.25	0.09	0.99	0.21	0.23
CV (%)	9.2	10.3	9.8	4.8	5.5
b. Sorghum (present crop)					
	Biomass, mg C kg^{-1} soil				
Previous crop					
Soybean	560	600	550	600	700
Sorghum	600	500	580	670	700
Fertilizer					
Control	550	510	520	610	660
Manure	640	620	600	720	770
N	550	510	560	580	660
Contrasts	(PR > F)				
Previous crop	0.43	0.16	0.12	<0.01	0.74
Fertilizer					
Manure vs. others	<0.01	<0.01	<0.01	<0.01	<0.01
Control vs. N	0.98	0.98	0.12	0.26	0.80
CV (%)	9.9	10.4	7.6	8.4	4.9

(Lynch and Panting, 1982; Santos and Clegg, 1983). Biomass C in the 0 to 30-cm depth interval represented 2.5 and 2.7% of organic C (calculated as 58% of organic matter) for soybean plots and sorghum plots, respectively. Microbial biomass in sorghum plots was positively correlated with sorghum root length in the 0 to 15 and 15 to 30-cm soil zone and with root dry weight in the 15 to 30-cm soil zone (Table 3). These data support the suggested synchrony between plant growth and soil microbial biomass (Doran and Smith, 1987; Lynch and Panting, 1980). Conclusions cannot be reached, however, whether plant growth affected soil microbial biomass or vice versa; although the first appears more likely. Increased root development will result in increased quantities of root exudates available which in turn would stimulate microbial growth. Other variables positively correlated with microbial biomass were water filled pore space for sorghum plots (0–15-cm depth) and bulk density for soybean plots (0–15-cm depth).

Table 3. Correlation values for microbial biomass with root length, root dry weight, and selected soil properties (summer 1986).

Variable	Soybean plots 0–15 cm	Soybean plots 15–30 cm	Sorghum plots 0–15 cm	Sorghum plots 15–30 cm
Root density	0.04	−0.08	0.55**	0.42*
Root dry weight	−0.29	−0.10	0.31	0.45*
Organic matter	0.04	−0.10	0.25	0.07
Total N	0.00	−0.04	0.32	0.04
Bulk density	0.50*	0.07	0.31	−0.10
Water-filled pore space	0.30	0.09	0.46*	0.03

*,** Indicate significant correlation at probability levels $P < 0.05$ and < 0.01, respectively.

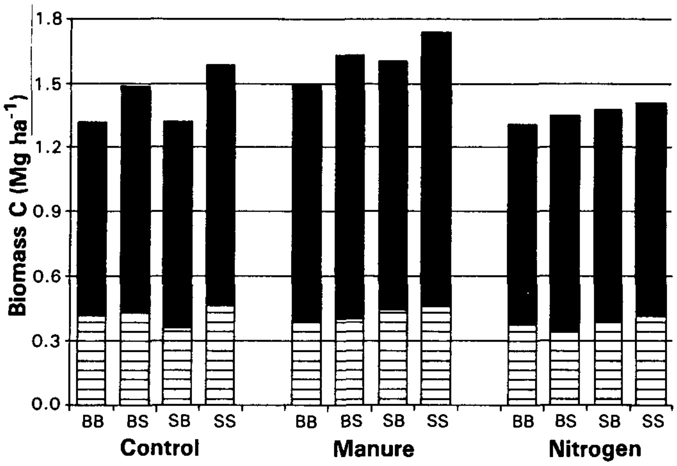

Fig. 1. Soil microbial biomass (Mg ha^{-1}) at 0–15 and 15–30 cm as influenced by cropping and fertilizer treatment. Cropping treatments consisted of continuous soybean (BB), soybean following sorghum (BS), sorghum following soybean (SB), and continuous sorghum (SS). Samples were collected in August 1986.

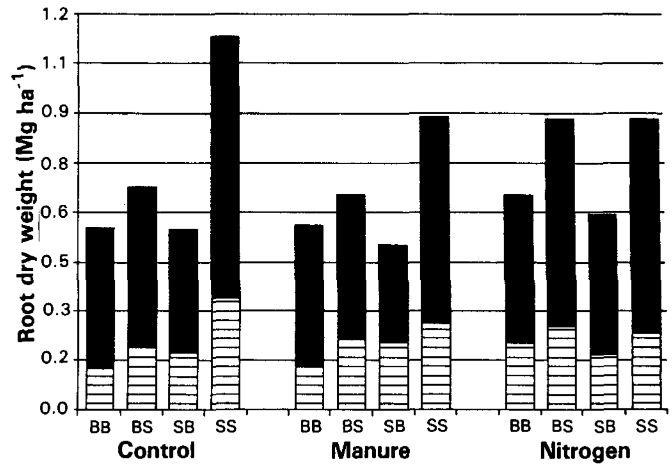

Fig. 2. Root dry weight of soybean and sorghum (Mg ha^{-1}) at 0–15 and 15–30 cm as influenced by cropping and fertilizer treatment. Crops and cropping treatments consisted of continuous soybean (BB), soybean following sorghum (BS), sorghum following soybean (SB), and continuous sorghum (SS). Samples were collected in August 1986.

No relationship was observed between microbial biomass and organic matter or total N content of the soil for either crop. These findings stand in contrast to reports by Adams and Laughlin (1981), Beck (1985), and Ross et al. (1980). Under the conditions of our study, however, differences in root growth between treatments likely influenced microbial biomass to a greater extent than differences in organic matter content which were less pronounced.

Root Dry Weight

Root dry weight of both crops showed a strong association with cropping and fertilizer treatment (Fig. 2, Table 4). Where the previous crop was sorghum instead of soybeans, root dry weights for the 0 to 30-cm depth and averaged over fertility treatments, were 26 and 77% greater for soybeans and sorghum, respectively. With manure and fertilizer N application root dry weights of sorghum were 18 and 12% lower than those from nonamended soils. Compared with the untreated control, however, soybean root dry weights were 25% higher where N was applied. The relationships between root growth and cropping or fertilizer treatment could partly result from differences in availability of soil N. Root dry weights were negatively correlated with soil nitrate levels (measured in the fall), with R values of -0.48 ($P = 0.02$) and -0.58 ($P < 0.01$) for the 0 to 15-cm depth and R values of -0.67 ($P < 0.01$) and -0.49 ($P = 0.01$) for the 15 to 30-cm depth, for soybeans and sorghum, respectively. Several authors have shown that root growth can be affected by physical resistance of soils (Voorhees et al., 1975; Gerik et al., 1987). Root dry weight and root density in this study, however, did not correlate with soil bulk density or volumetric water content.

Organic Matter Content

With manure amendment soil organic matter content was increased by 16.3 and 5.5% in the 0 to 15- and 15 to 30-cm depth interval (averaged over cropping treatments), respectively (Fig. 3, Table 4). Crop-

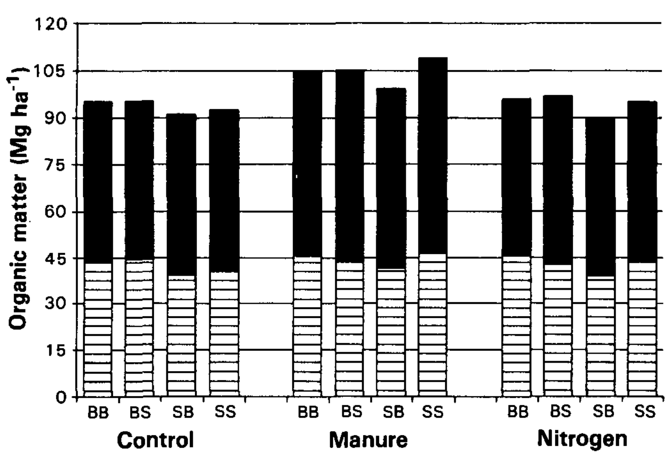

Fig. 3. Soil organic matter content (Mg ha^{-1}) at 0–15 and 15–30 cm as influenced by cropping and fertilizer treatment. Cropping treatments consisted of continuous soybean (BB), soybean following sorghum (BS), sorghum following (SB), and continuous sorghum (SS). Samples were collected in October 1986.

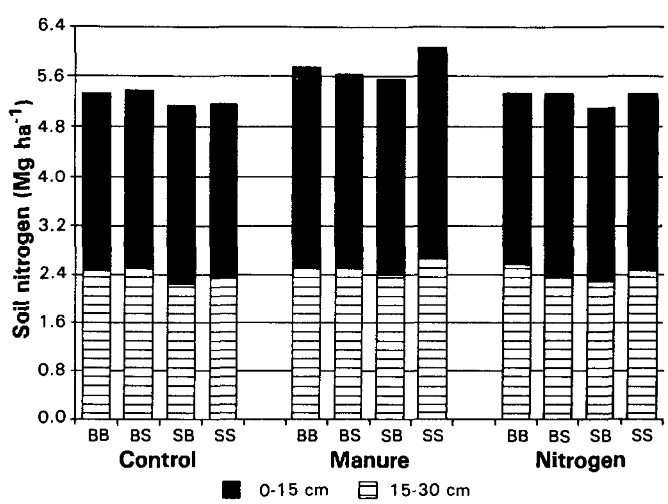

Fig. 4. Soil N content (Mg ha^{-1}) at 0–15 and 15–30 cm as influenced by cropping and fertilizer temperature. Cropping treatments consisted of continuous soybean (BB), soybean following sorghum (BS), sorghum following soybean (SB), and continuous sorghum (SS). Samples were collected in October 1986.

Table 4. Probability (PR > *F*) values of orthogonal contrasts comparing effects of cropping and fertilizer treatment on microbial biomass C, soil organic matter, total N, and root dry weight at 0- to 15- and 15- to 30-cm depth and corresponding coefficients of variation (CV) in 1986.

	Biomass C		Organic matter		Total N		Root dry weight	
Contrasts	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
			a. Soybean (present crop)					
Previous crop (PC)	<0.01	0.87	0.13	0.36	0.84	0.54	0.07	0.02
Fertilizer								
Manure vs. others	<0.01	0.80	<0.01	0.70	<0.01	0.56	0.21	0.38
Control vs. N	0.76	0.05	0.65	0.82	0.90	0.74	0.12	0.04
PC × fertilizer	0.55	0.78	0.39	0.64	0.35	0.35	0.30	0.88
CV (%)	7.8	13.9	5.5	8.7	6.5	7.3	22.2	33.3
			b. Sorghum (present crop)					
Contrasts (PR < *F*)								
Previous crop (PC)	0.07	0.14	0.31	<0.01	0.38	<0.01	<0.01	<0.01
Fertilizer								
Manure vs. others	<0.01	0.22	<0.01	0.04	<0.01	<0.01	0.04	0.92
Control vs. N	0.40	0.92	0.61	0.39	0.73	0.23	0.40	0.13
PC × fertilizer	0.47	0.49	0.34	0.55	0.18	0.48	0.21	0.25
CV (%)	11.5	18.6	6.8	7.4	5.4	6.2	18.7	31.1

ping treatment showed no effect on the organic matter content of soybean plots. For sorghum after soybean plots the organic matter content at the 15 to 30-cm depth, however, was 13% lower than that with continuous sorghum. This could be the result of reduced root mass production at this soil depth with sorghum following soybean.

Nitrogen Content

Total soil N content (Fig. 4) was highly correlated with soil organic matter content with correlation values of 0.91 and 0.96 for the 0 to 15- and 15 to 30-cm depths, respectively (averaged over all treatments). Analysis of variance declared the same effects significant for both organic matter and total N content of the soil (Table 4). The C/N ratio for the 0 to 15-cm depth of soybean plots was 10.4, 11.0, and 10.5 for the fertilizer treatments control, manure, and N fertilizer, respectively (contrast manure vs. others $P = 0.04$). No other treatment effects on the C/N ratio were identified.

Table 5. Dry matter and N accumulation of shoot, root and microbial biomasses influenced by cropping and fertilizer treatment (measured August 1986).

	Shoot		Root†		Microbial biomass‡		Total	
Treatment	DM	N	DM	N§	DM¶	N#	DM	N
			a. Soybean (present crop)					
Previous crop					Mg ha^{-1}			
Soybean	6.6	0.18	1.1	0.02	2.7	0.16	10.4	0.36
Sorghum	6.3	0.18	1.4	0.03	3.0	0.17	10.7	0.38
Fertilizer								
Control	6.1	0.17	1.2	0.02	2.8	0.16	10.1	0.36
Manure	6.5	0.19	1.1	0.02	3.1	0.18	10.8	0.39
N	6.7	0.18	1.4	0.03	2.7	0.15	10.8	0.36
Contrasts					(PR > *F*)			
Previous crop (PC)	0.28	0.77	<0.01		<0.01		0.28	0.04
Fertilizer								
Manure vs. others	0.58	0.41	0.01		<0.01		0.29	<0.01
Control vs. N	0.04	0.42	0.02		0.07		0.04	0.70
PC × fertilizer	015	0.07	0.11		0.24		0.11	0.04
			b. Sorghum (present crop)					
Previous crop					Mg ha^{-1}			
Soybean	11.7	0.16	1.1	0.01	2.9	0.17	15.6	0.33
Sorghum	9.8	0.11	1.8	0.02	3.2	0.18	14.8	0.31
Fertilizer								
Control	9.3	0.09	1.6	0.02	2.9	0.17	13.8	0.28
Manue	11.8	0.15	1.4	0.01	3.3	0.19	16.6	0.36
N	11.1	0.15	1.4	0.01	2.8	0.16	15.3	0.33
Contrasts					PR > *F*)			
Previous crop (PC)	<0.01	<0.01	<0.01		0.03		0.06	0.03
Fertilizer								
Manure vs. others	<0.01	<0.01	0.52		<0.01		<0.01	<0.01
Control vs. N	<0.01	<0.01	0.04		0.46		<0.01	<0.01
PC × fertilizer	<0.01	0.06	0.21		0.35		<0.01	0.42

† Root estimates for 0- to 120-cm depth.
‡ Microbial biomass estimates for 0- to 30-cm depth.
§ Estimated assuming N content of 1.8% for soybean (Hanway and Weber, 1971) and 1% for sorghum.
¶ Assuming C as 50% of dry matter.
# Assuming N content as 5.8% of dry matter.

Productivity

The total ecological productivity of the cropping systems, defined here to include above and below ground plant matter and microbial biomass, expressed as dry matter and N content, is shown in Table 5. Cropping and fertilizer treatment affected dry matter and N partitioning between shoot, root and microbial biomass.

Soybean shoot dry matter was increased by manure and N fertilizer, while the previous crop showed no effect. Below ground productivity, consisting of root dry matter and microbial biomass, was higher, however, if the previous crop was sorghum instead of soybeans. Therefore shoot dry matter represented a lower proportion of total productivity; 63% for continuous soybeans and 59% for soybeans following sorghum.

Sorghum shoot dry matter was increased with soybeans as previous crop, and with manure, or N fertilizer. Sorghum shoot dry matter as a proportion of total productivity increased from 67% for the control to 71 and 73% for manure and N fertilized treatments, respectively. Again, below ground productivity was higher where the previous crop was sorghum instead of soybean, and sorghum shoot dry matter represented a lower proportion of total productivity (66 vs. 75%). The 1.9 Mg ha^{-1} shoot dry matter increase with sorghum after soybeans, compared with continuous sorghum, was accompanied by a decrease in root mass and microbial biomass of 1 Mg ha^{-1}. Consequently differences in total productivity were less pronounced. With continuous cropping of sorghum a greater proportion of total productivity occurs below ground and less above ground.

CONCLUSIONS

Cropping system influenced both microbial biomass and rooting patterns in the surface 0 to 30 cm of soil. Microbial biomass levels with sorghum as present or previous crop were 0.3 to 0.5 Mg ha^{-1} (0.15–0.25 Mg C ha^{-1}) greater than where soybeans was the present or previous crop. Where sorghum was the previous crop root dry matter was 0.7 and 0.3 Mg ha^{-1} greater than where soybeans was the previous crop. In our study, soil microbial biomass levels were closely associated with root dry matter levels of sorghum but not soybeans. Cropping systems, however, had little effect on overall levels of soil organic C and N, although crop rotation and manure application did increase microbial biomass levels by 0.3 Mg ha^{-1}.

Previous crop affected dry matter partitioning between above ground crop growth and below ground pools of roots, microbial biomass, and organic matter for both crops. With sorghum as previous crop a consistently higher proportion of the total production occurred below ground and less above ground.

REFERENCES

Adams, J.E. 1974. Residual effects of crop rotations on water intake, soil loss, and sorghum yield. Agron. J. 66:299–304.

Adams, T.McM., and R.J. Laughlin. 1981. The effects of agronomy on the carbon and nitrogen contained in the soil biomass. J. Agric. Sci. 97:319–327.

Anderson, J.P.E., and K.H. Domsch. 1978. A physiological method for the quantitative measurement of microbial biomass in soils. Soil Biol. Biochem. 10:215–221.

Beck, T. 1985. The influence of different agricultural treatments on the relative stability of organic matter in soils. Landwirtsch. Forsch. 38:1–7.

Biederbeck, V.O., C.A. Campbell, and R.P. Zenter. 1984. Effect of crop rotation and fertilization on some biological properties of a loam in southwestern Saskatchewan. Can. J. Soil Sci. 64:355–367.

Bolton, H. Jr., L.F. Elliott, R.I. Papendick, and D.F. Bezdicek. 1985. Soil microbial biomass and selected soil enzyme activities: effect of fertilization and cropping practices. Soil Biol. Biochem. 17:297–302.

Bosch, M., and A. Amberger. 1983. Influence of long-term fertilizing with different forms of nitrogen fertilizer on pH, humic fractions, biological activity and dynamics of nitrogen of an arable brown earth. Z. Pflanzenernaehr. Bodenk. 146:714–724.

Campbell, C.A., M. Schnitzer, J.W.B. Stewart, V.O. Biederbeck and F. Selles. 1986. Effect of manure and P fertilizer on properties of a Black Chernozem in Southern Saskatchewan. Can. J. Soil Sci. 66:601–613.

Clegg, M.D., C.Y. Sullivan, and J.D. Eastin. 1978. A sensitive technique for the rapid measurement of carbon dioxide concentrations. Plant Physiol. 62:924–926.

Doran, J.W., and M.S. Smith. 1987. Organic matter management and utilization of soil and fertilizer nutrients. p. 53–72. *In* R.F. Follett (ed.) Soil fertility and organic matter as critical components of production systems. Spec. Pub. 19. SSSA, Madison, WI.

Fahad, A.A. 1979. Physical properties of soil and root distribution as affected by soybean cropping sequence. Ph.D. diss. Univ. of Nebraska. (Diss Abstr. 80-09584).

Fahad, A.A., L.N. Mielke, A.D. Flowerday, and D. Swartzendruber. 1982. Soil physical properties as affected by soybean and other cropping sequences. Soil Sci. Soc. Am. J. 46:377–381.

Gerik, T.J., J.E. Morrison, Jr., and F.W. Chichester. 1987. Effects of controlled-traffic on soil physical properties and crop rooting. Agron. J. 79:434–438.

Hageman, N.R., and W.D. Shrader. 1979. Effects of crop sequence and N-fertilizer levels on soil bulk density. Agron. J. 21:1005–1008.

Hanway, J.J., and C.R. Weber. 1971. N, P, and K percentages in soybean [*Glycine max* (L.) Merr.] plant parts. Agron. J. 63:286–290.

Lynch, J.M., and L.M. Panting. 1980. Cultivation and the soil biomass. Soil Biol. Biochem. 12:29–33.

Lynch, J.M., and L.M. Panting. 1982. Effects of season, cultivation and nitrogen fertilizer on the size of the soil microbial biomass. J. Sci. Food Agric. 33:249–252.

McGill, W.B., K.R. Cannon, J.A. Robertson, and F.D. Cook. 1986. Dynamics of soil microbial biomass and water-soluble organic C in Breton L after 50 years of cropping to two rotations. Can. J. Soil Sci. 66:1–19.

Ross, D.J., K.R. Tate, A. Cairns, and E.A. Pansier. 1980. Microbial biomass estimations in soils from tussock grasslands by three biochemical procedures. Soil Biol. Biochem. 12:375–383.

Rosswall, T., and K. Paustian. 1984. Cycling of nitrogen in modern agricultural systems. Plant Soil. 76:3–21.

Santos, J.R., and M.D. Clegg. 1983. Dinitrogen fixation and biomass production under different sorghum and soybean cropping patterns with four fertilizer rates. Agronomy Abstracts, ASA, Madison, WI., p. 114.

Schulte, E.E. 1980. Recommended soil organic matter tests. p. 28–31. *In* Recommended chemical soil test procedures for the North Central Region. North Central Regional Publ. no. 221. Fargo, ND 58105.

Smith, J.L., B.L. McNeal, and H.H. Cheng. 1985. Estimation of soil microbial biomass: an analysis of the respiratory response of soils. Soil Biol. Biochem. 17:11–16.

Smith, R.M., and R.C. Henderson. 1967. Summary of soil and water conservation research from the Blackland Conservation Field Station, Temple, Texas. USDA-ARS Res. Rep. no. 393. Temple, TX.

Smucker, A.J.M. 1984. Carbon utilization and losses by plant root systems. p. 27–46. *In* Roots, nutrient and water influx, and plant growth. Special Pub. 49. ASA, Madison, WI.

Sommerfeldt, T.G., and C. Chang. 1986. Soil-water properties as affected by twelve annual applications of cattle feedlot manure. Soil Sci. Soc. Am. J. 51:7–9.

Tennant, D. 1975. A test of a modified line intersect method of estimating root length. J. Ecol. 63:995–1001.

Unger, P.W., and B.A. Stewart. 1974. Feedlot waste effects on soil conditions and water evaporation. Soil Sci. Soc. Am. Proc. 38:954–957.

Voorhees, W.B., D.A. Farrell, and W.E. Larson. 1975. Soil strength and aeration effects on root elongation. Soil Sci. Soc. Am. Proc. 39:948–953.

Wood, W. 1987. Predicted microbial biomass in the rhizosphere of barley in the field. Plant Soil 97:303–314.